United States Nuclear Regulatory Commission
Protecting People and the Environment

Assessment of BTP 5-3 Protocols to Estimate $RT_{NDT(u)}$ and USE

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Outline of Presentation

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- Un-Irradiated RT_{NDT} ($RT_{NDT(u)}$) & Un-Irradiated Upper Shelf Energy (USE) definitions & estimates
- Background of questions concerning BTP 5-3
- Staff Assessment Part I - Technical evaluation of BTP 5-3 estimation of $RT_{NDT(u)}$ & USE
- Staff Assessment Part I – Potentially Affected Plants
- Next steps

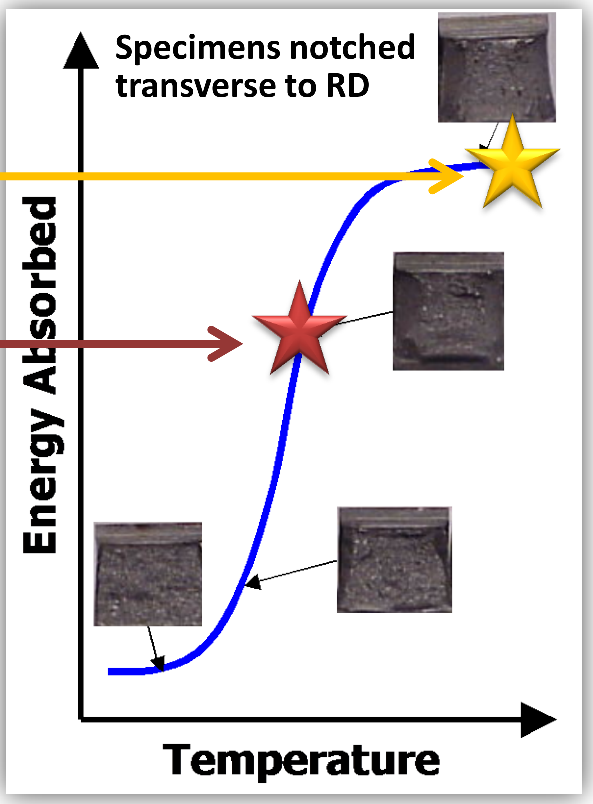
Definitions: $RT_{NDT(u)}$ & USE

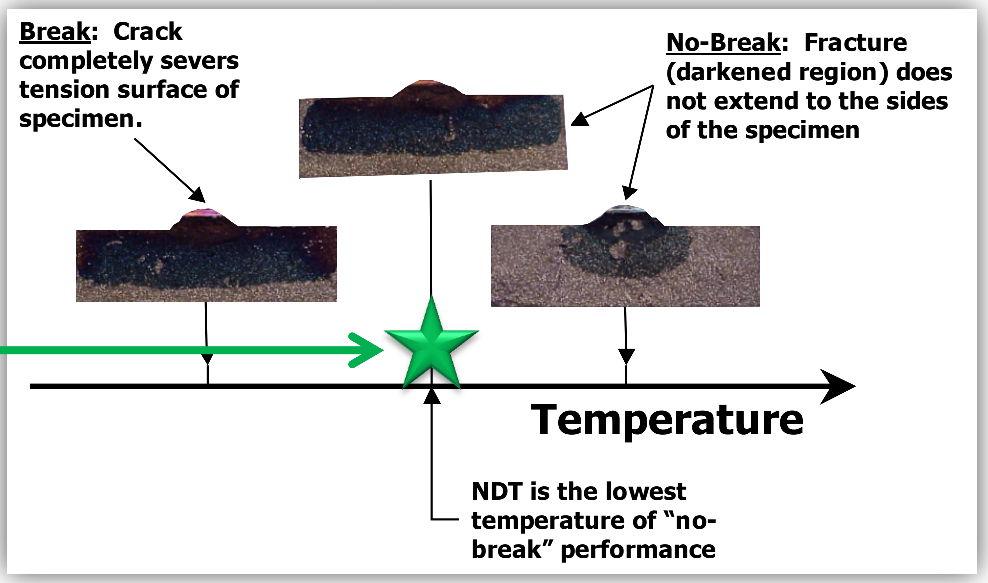
$$USE \equiv \text{average of all energies} > 95\% \text{ shear}$$

per ASTM E185-82

$$RT_{NDT(u)} = MAX\left\{T_{NDT}, T_{35/50} - 60\right\}$$

per ASME NB-2331





$RT_{NDT(u)}$ & USE

Estimated by NUREG-0800 BTP 5-3

Approximations

Position 1.1(4)

Positions 1.1(1) & 1.1(2)

Position 1.1(3)

$$\boxed{RT_{NDT(u)}} = MAX\left\{\boxed{T_{NDT}}, \boxed{T_{35/50}} - 60\right\}$$

per ASME NB-2331

Position 1.2

$\boxed{USE} \equiv$ average of all energies > 95% shear

per ASTM E185-82

Background of Questions Concerning BTP 5-3

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- AREVA Letter (30 Jan 2014, AREVA Ref. NRC:14:004) & PVP Paper (PVP2014-28897) claim Position 1.1(4) of BTP 5.3 is sometimes non-conservative for A508-2 forgings

- Literature search reveals 1983 EG&G report & 1985 IJPVP paper
  - Evaluation of BTP 5-3 (then MTEB 5-2) for NRC
  - Conclusions
    - Always conservative
      - Position 1.1(1): estimates T_{NDT}
      - Position 1.1(2): estimates T_{NDT}
    - Sometime non-conservative
      - Position 1.1(3): estimates $T_{CVE(50/35)}$
      - Position 1.1(4): estimates RT_{NDT}
      - Position 1.2: estimates USE

AREVA

January 30, 2014
NRC:14:004

U.S. Nuclear Regulatory Commission
Document Control Desk
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Rockville, MD 20852

Potential Non-Conservatism in NRC Branch Technical Position 5-3

DRAFT

Proceedings of the ASME 2014 Pressure Vessels & Piping Conference
PVP2014
July 20-24, 2014, Anaheim, California, USA

PVP2014-28897

AN ASSESSMENT OF BRANCH TECHNICAL POSITION 5-3 TO DETERMINE UNIRRADIATED RT_{NDT} FOR SA-508 CL. 2 FORGINGS

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Background of Questions Concerning BTP 5-3

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- AREVA Letter (30 Jan 2014, AREVA Ref. NRC:14:004) & PVP Paper (PVP2014-28897) claim Position 1.1(4) of BTP 5.3 is sometimes non-conservative for A508-2 forgings

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      - Position 1.1(3): estimates $T_{CVE(50/35)}$
      - Position 1.1(4): estimates RT_{NDT}
      - Position 1.2: estimates USE

EGG-MS-6310

CORRELATION OF CHARPY V-NOTCH DATA WITH FRACTURE TOUGHNESS PARAMETERS FOR SA-533B-1 AND SA-508-2 STEELS

P. K. Nagata
W. G. Reuter
A. K. Richardson
W. L. Server

Published December 1983

Int. J. Pres. Ves. & Piping **19** (1985) 299–315

Adequacy of Estimates and Variability of Fracture-related Properties for Reactor Pressure Vessel Materials*

A. K. Richardson, W. L. Server & W. G. Reuter

E.G. & G. Idaho, Inc., PO Box 1625, Idaho Falls, Idaho 83415, USA

(Received: 3 October, 1984)

NRC Staff Assessment Process

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Part I: Technical evaluation of BTP 5-3 estimation of $RT_{NDT(u)}$ and USE

- Data sources
  - Processed data (T_{50}, USE, …) from 1983 EG&G report
  - Raw data (CVE, MLE, temp) in both specimen orientations from surveillance reports (stored in REAP)
  - Raw data (NDTT) from RVID refs.
- Focus on
  - Plates & forgings only
    - No plants have used BTP 5-3 for welds
  - Positions identified as sometimes non-conservative in 1983 by EG&G report
    - Position 1.1(3): estimates $T_{CVE(50/35)}$
    - Position 1.1(4): estimates RT_{NDT}
    - Position 1.2: estimates USE

Part II: Assessment of applicability to plants

- Query RVID
  - $RT_{NDT(u)}$: establishes BTP 5-3 use, but not which position was used
  - USE: establishes BTP 5-3 use
- Search for documents referenced by RVID in ADAMS legacy
  - Focus on plants closest to PTS (50.61) limit, these being most prone to influence by potential non-conservatisms
  - References establish which position of BTP 5-3 was used for $RT_{NDT(u)}$

Part I: Technical Evaluation

Overview

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- Data sources
  - Processed data (T_{50}, USE, …) from 1983 EG&G report
  - Raw data (CVE, MLE, temp) from surveillance reports (stored in REAP)
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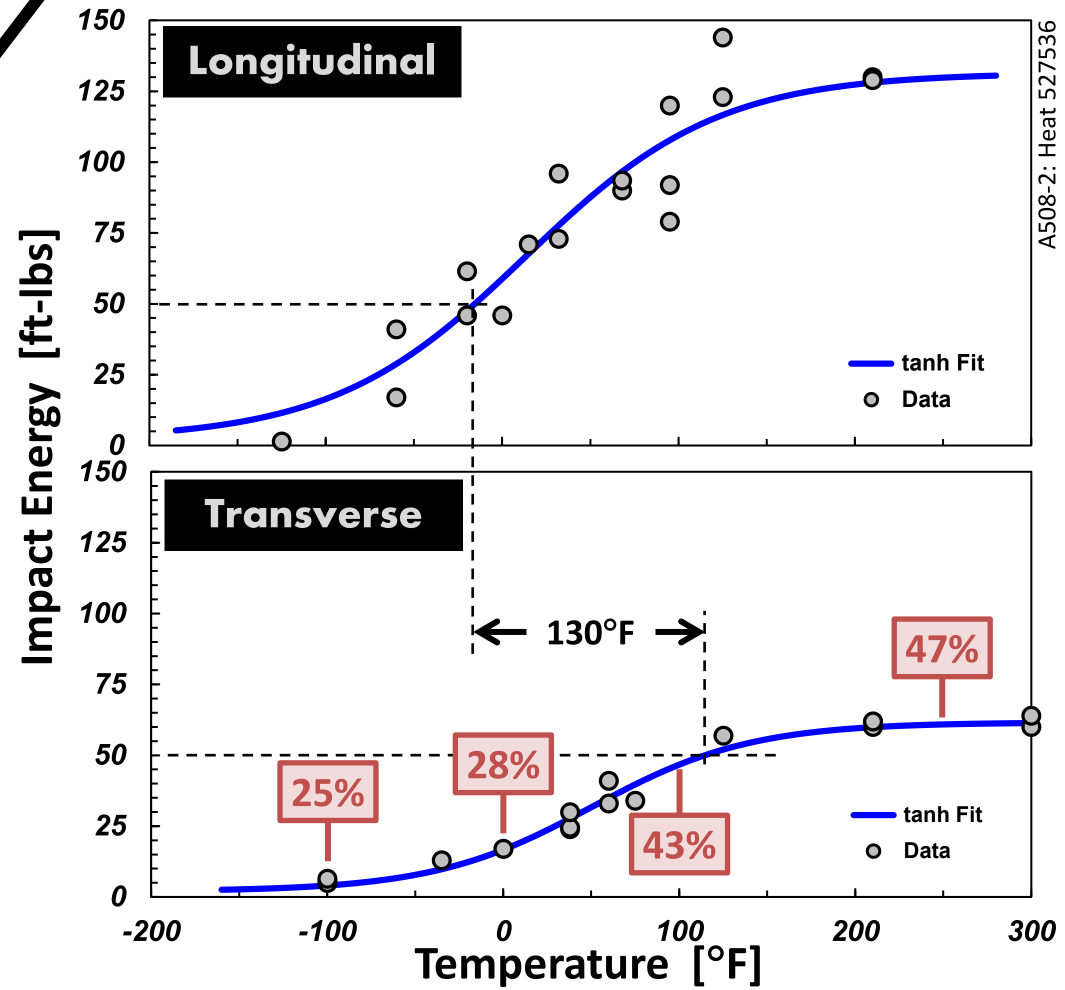
- Focus on
  - Plates & forgings only
    - No plants have used BTP 5-3 for welds
  - Positions identified as sometimes non-conservative by 1983 EG&G report
    - Position 1.1(3): estimates $T_{CVE(50/35)}$
    - Position 1.1(4): estimates RT_{NDT}
    - Position 1.2: estimates USE

- **While similar answers are expected from both sources …**
- **Given the potential impact of this evaluation, going back to the raw data was seen to be important.**



Position 1.1(3)

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Quotation

If transversely-oriented Charpy V-notch specimens were not tested, the temperature at which 68 J (50 ft-lbs) and 0.89 mm (35 mils) LE would have been obtained on transverse specimens may be estimated by one of the following criteria:

- Test results from longitudinally-oriented specimens reduced to 65% of their value to provide conservative estimates of values expected from transversely oriented specimens.
- Temperatures at which 68 J (50 ft-lbs) and 0.89 mm (35 mils) LE were obtained on longitudinally-oriented specimens increased 11 °C (20 °F) to provide a conservative estimate of the temperature that would have been necessary to obtain the same values on transversely-oriented specimens.

Tests Required

Longitudinally oriented CVN specimens

Clear Interpretation

Note that this position applies only to conversion between longitudinal and transverse Charpy values.

There are two approximations. They may not produce the same results. They are as follows

(a) $E_{TRANS} = 0.65 \times E_{LONG}$, then calc $T_{C(TRANS)}$
$MLE_{TRANS} = 0.65 \times MLE_{LONG}$, then calc $T_{C(TRANS\text{-}MLE)}$

(b) $T_{C(TRANS)} = T_{C(LONG)} + 20\ °F$
$T_{C(TRANS\text{-}MLE} = T_{C(LONG\text{-}MLE)} + 20\ °F$

where

E_{LONG}	is CVN energy measured by a longitudinally oriented specimen
E_{TRANS}	is the estimated CVN for a transversely oriented specimen
$T_{C(LONG)}$	is the temperature at which the minimum of three longitudinal CVN tests exhibits >35 mils AND >50 ft-lbs
$T_{C(TRANS)}$	is the estimated temperature at which the minimum of three transverse CVN tests exhibits >35 mils AND >50 ft-lbs

Position 1.1(3)

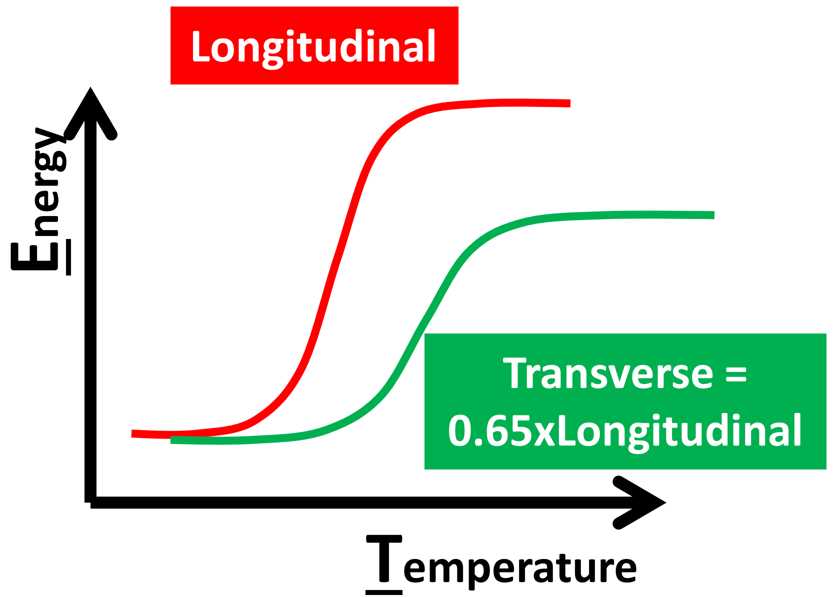
Assessing(a): Trans = 0.65×Long

1. Per the BTP, reduce longitudinal measurements to 65% of the measured values

2. Fit Charpy curves
   - Energy vs. temperature
   - Lateral expansion vs. temperature

3. Determine MAX($T_{50ft\text{-}lb}$, $T_{35mills}$)

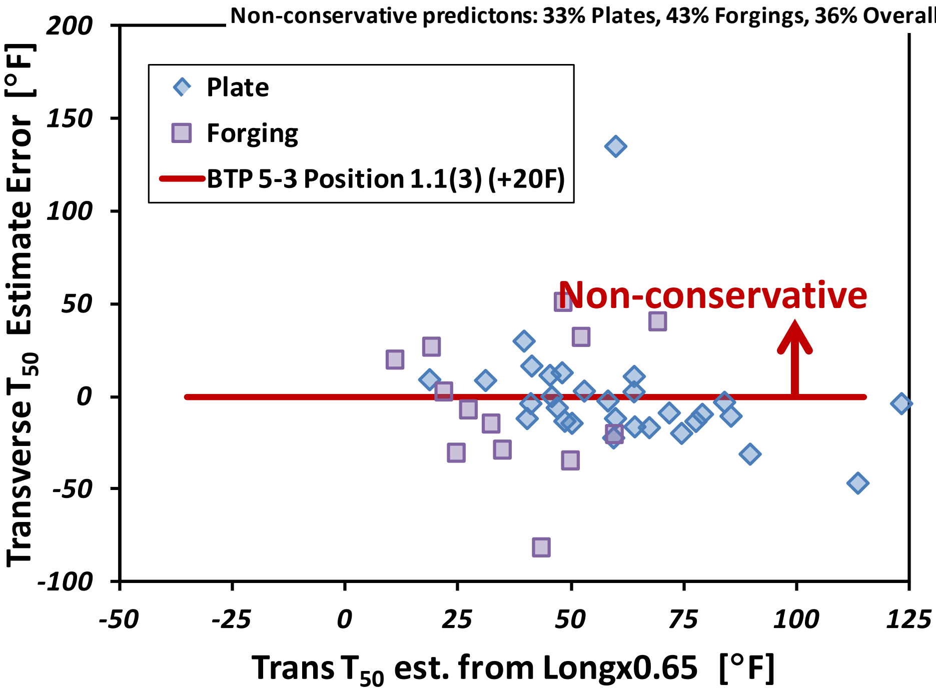
4. Value from Step 3 estimates the transition temperature of transverse data

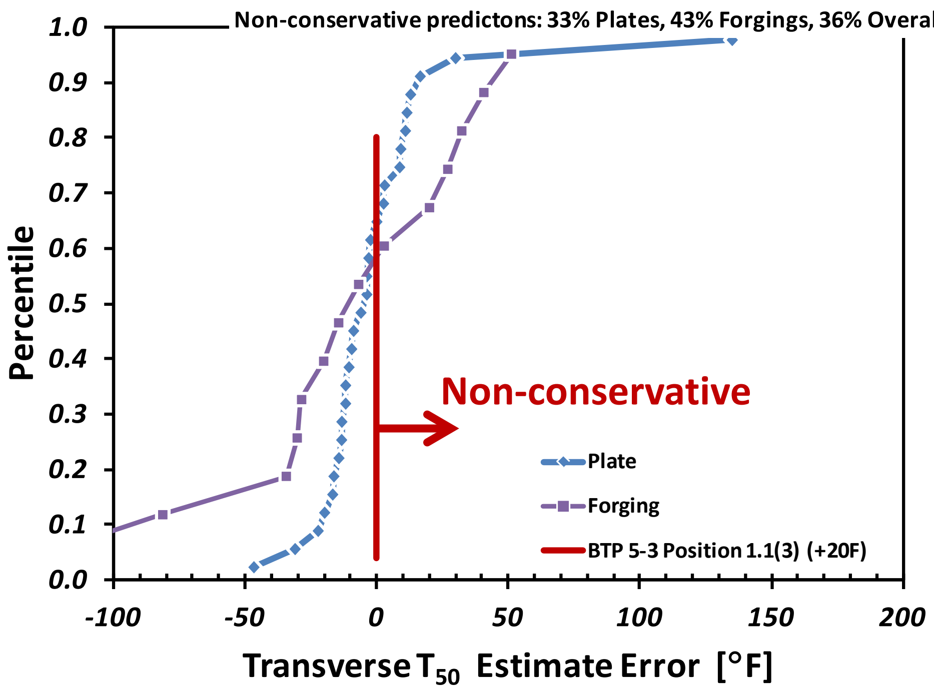


Position 1.1(3)

Assessing(a): Trans = 0.65×Long

Same data plotted two different ways





Position is non-conservative about 36% of the time

EG&G Data

Position 1.1(3)

Assessing(a): Trans = 0.65×Long

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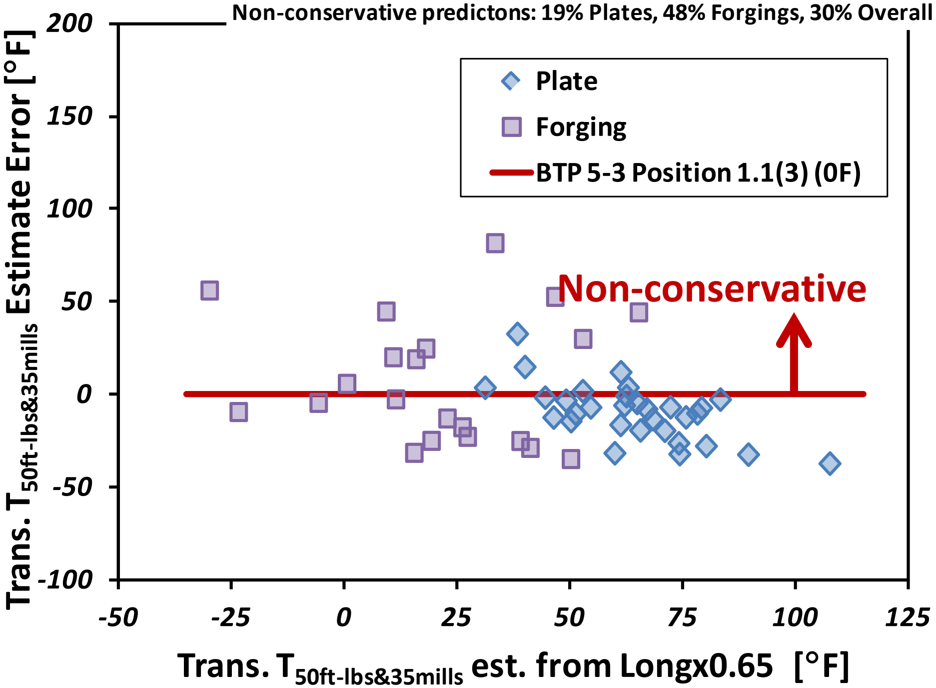
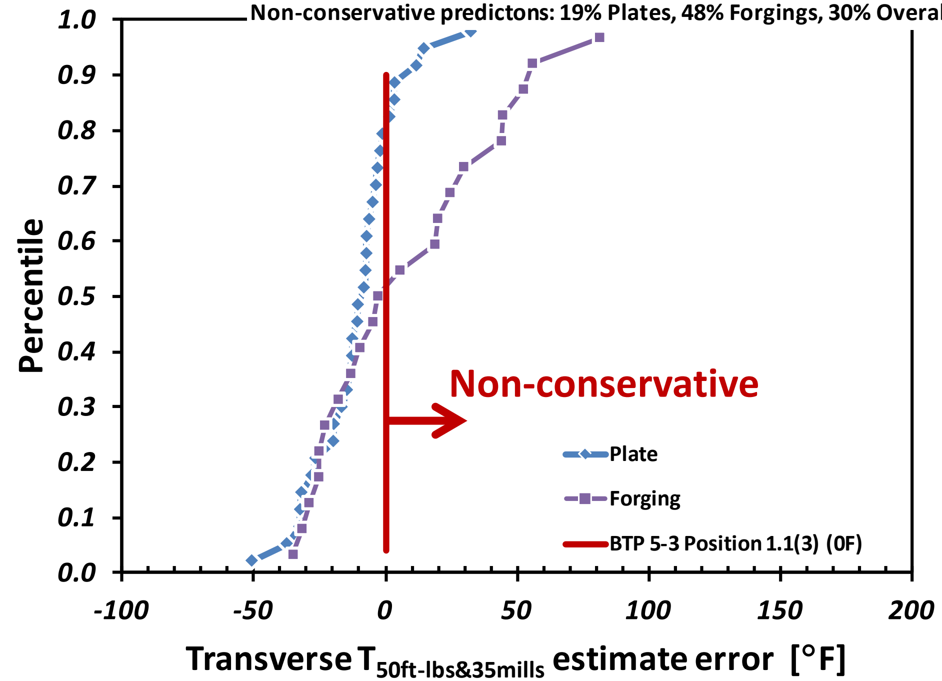
Same data plotted two different ways





$T_{50ft\text{-}lbs}$ determines the value of $T_{50ft\text{-}lbs\&35mills}$

- 81% of the time for longitudinal specimens
- 92% of the time for transverse specimens

Position is non-conservative about 30% of the time

Raw Data

Position 1.1(3)

Assessing(b): Alternative $T_{C(TRANS)}$ Estimates

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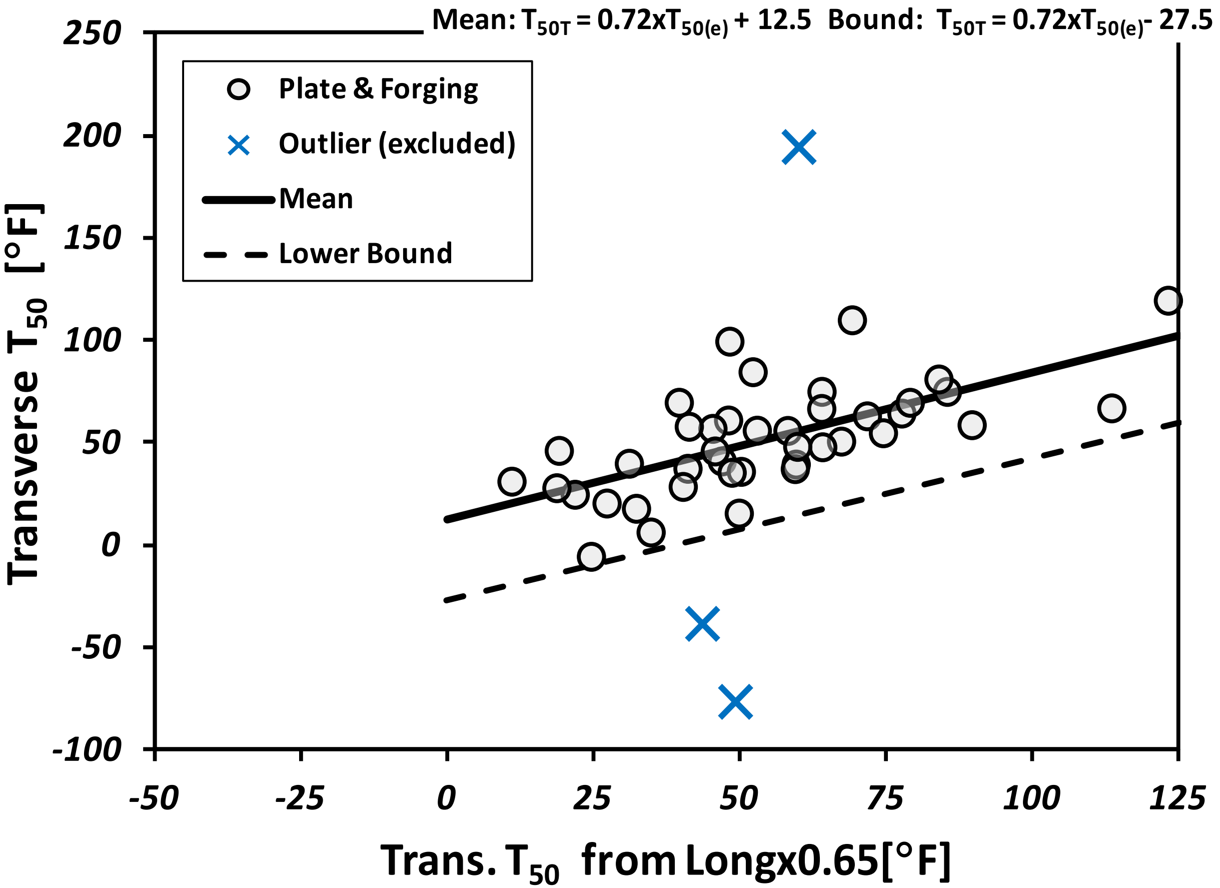
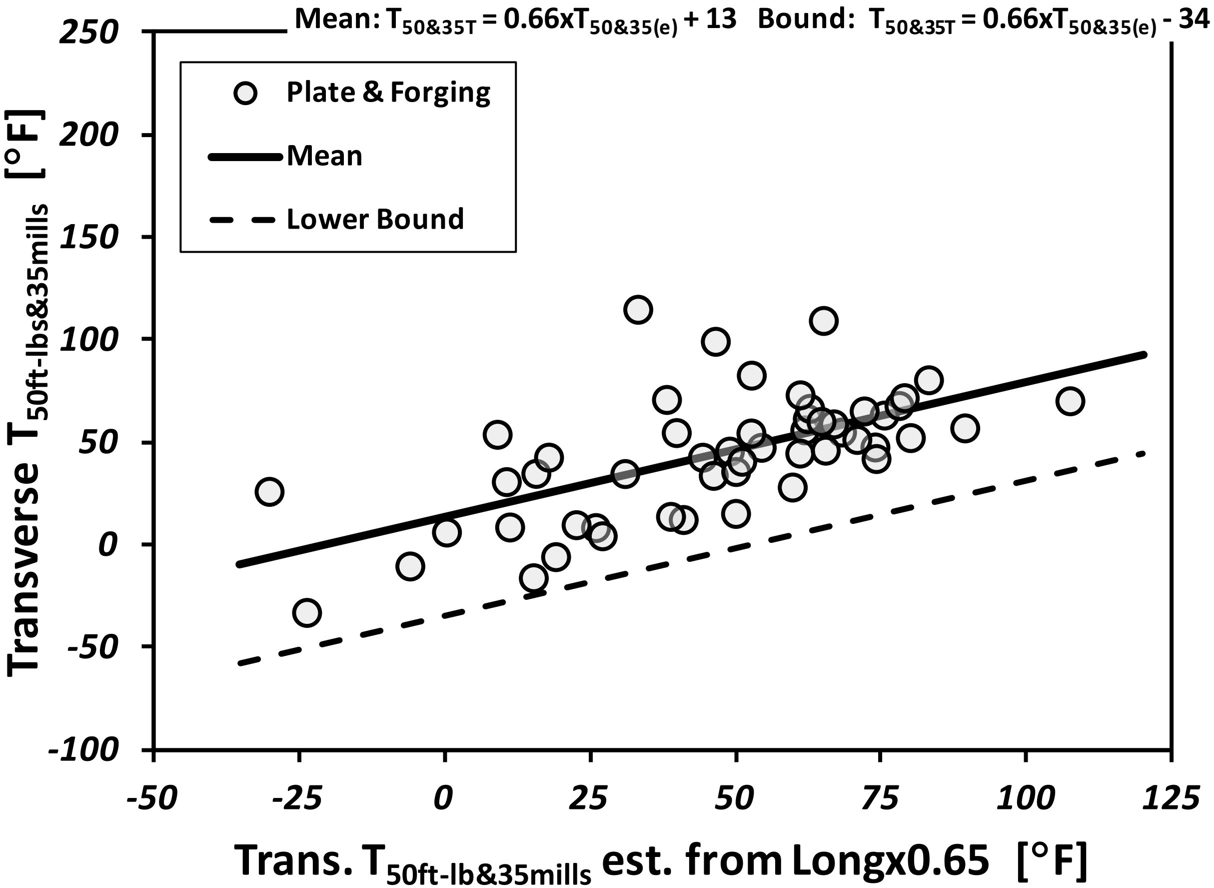


Preliminary analysis suggests that alternative formulae could be developed to convert longitudinal to transverse T_{50} values in a manner that is always conservative.

EG&G Data

Position 1.1(3)

Assessing(a): Alternative $T_{C(TRANS)}$ Estimates



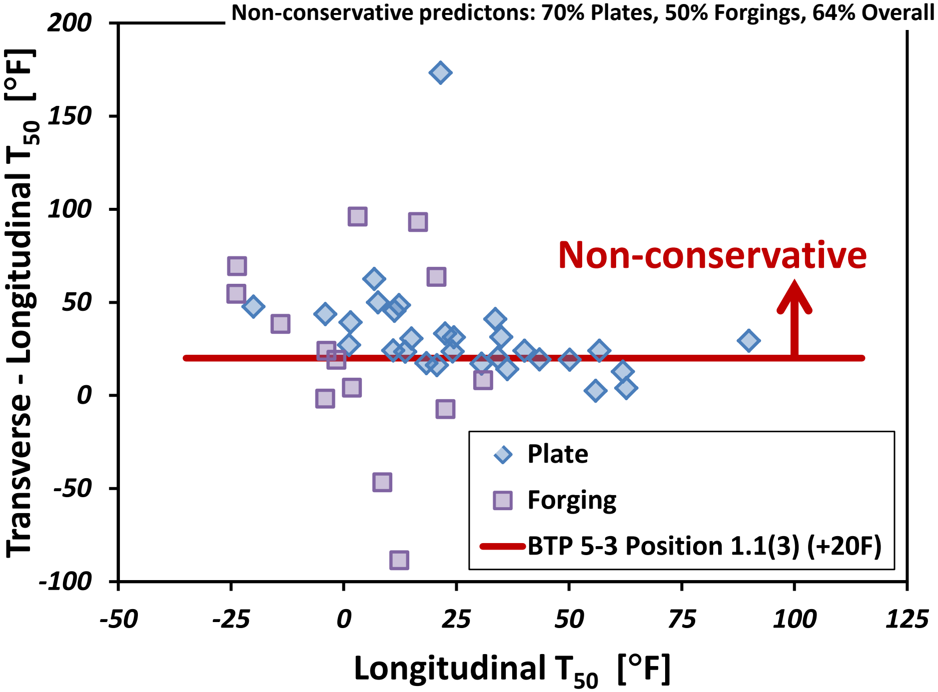
Preliminary analysis suggests that alternative formulae could be developed to convert longitudinal to transverse T_{50} values in a manner that is always conservative.

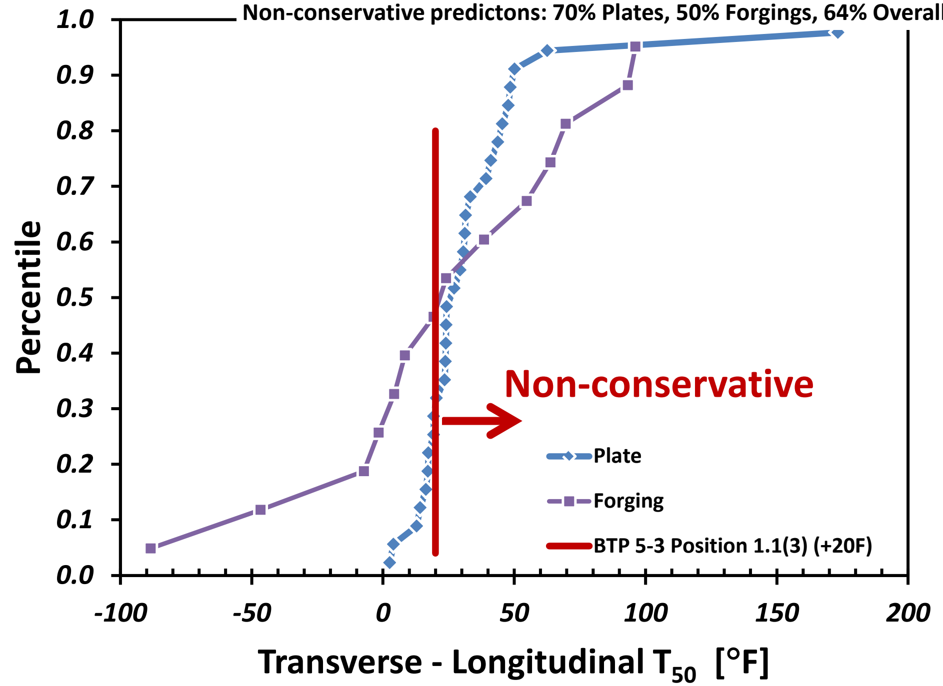
Raw Data

Position 1.1(3)

Assessing(b): $T_{C(TRANS)} = T_{C(LONG)} + 20\ °F$

Same data plotted two different ways





Position is non-conservative about two-thirds of the time

EG&G Data

Position 1.1(3)

Assessing(b): $T_{C(TRANS)} = T_{C(LONG)} + 20\ °F$

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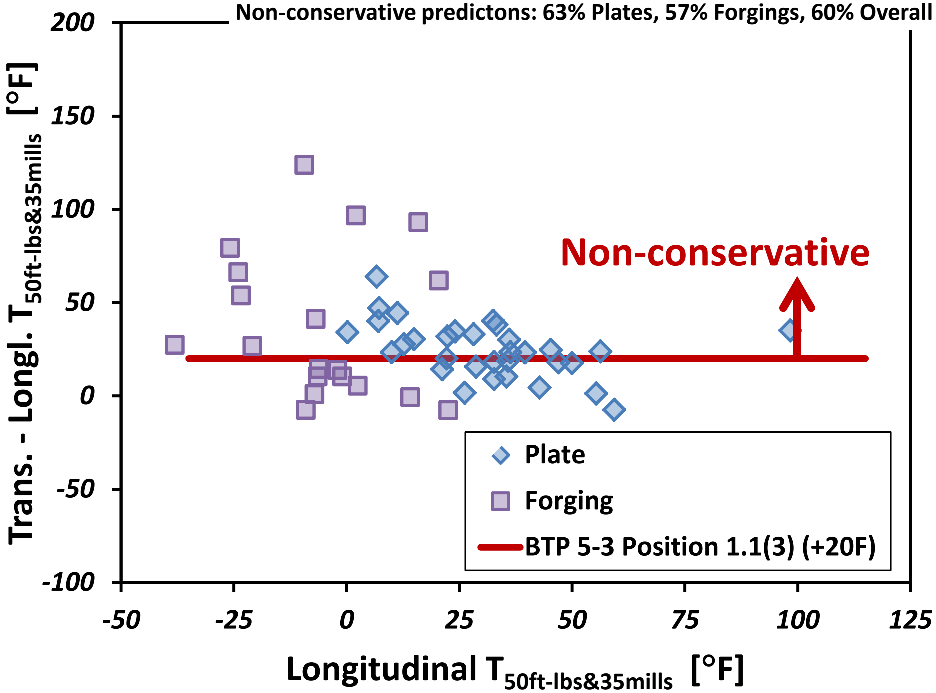
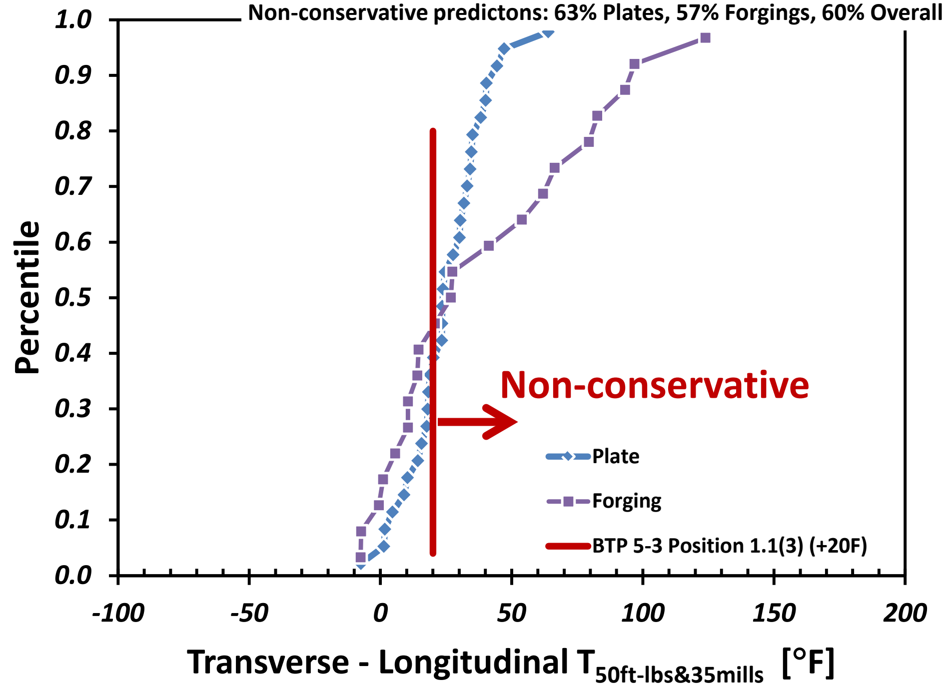
Same data plotted two different ways





$T_{50ft\text{-}lbs}$ determines the value of $T_{50ft\text{-}lbs\&35mills}$

- 81% of the time for longitudinal specimens
- 92% of the time for transverse specimens

Position is non-conservative about two-thirds of the time

Raw Data

Position 1.1(3)

Assessing(b): Alternative $T_{C(TRANS)}$ Estimates

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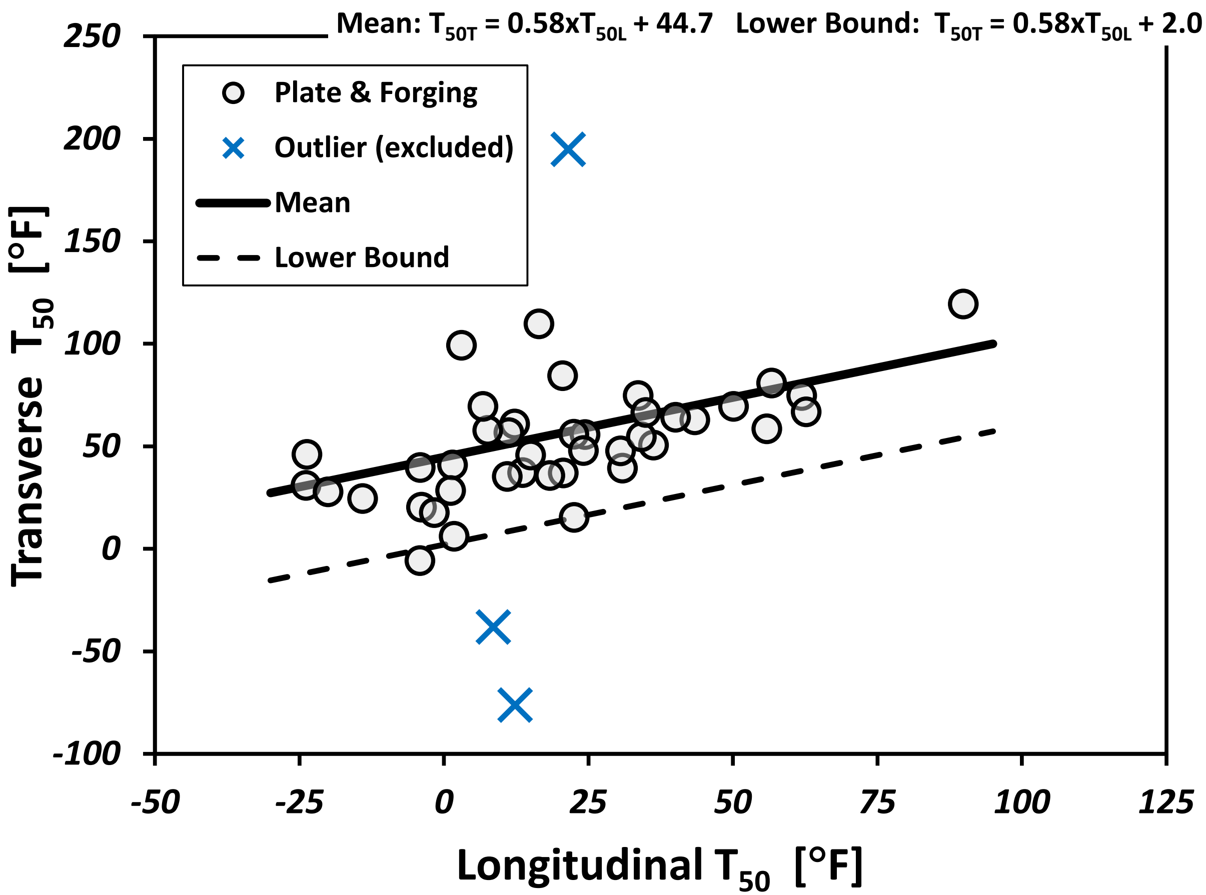

Preliminary analysis suggests that alternative formulae could be developed to convert longitudinal to transverse T_{50} values in a manner that is always conservative.

EG&G Data

Position 1.1(3)

Assessing(b): Alternative $T_{C(TRANS)}$ Estimates

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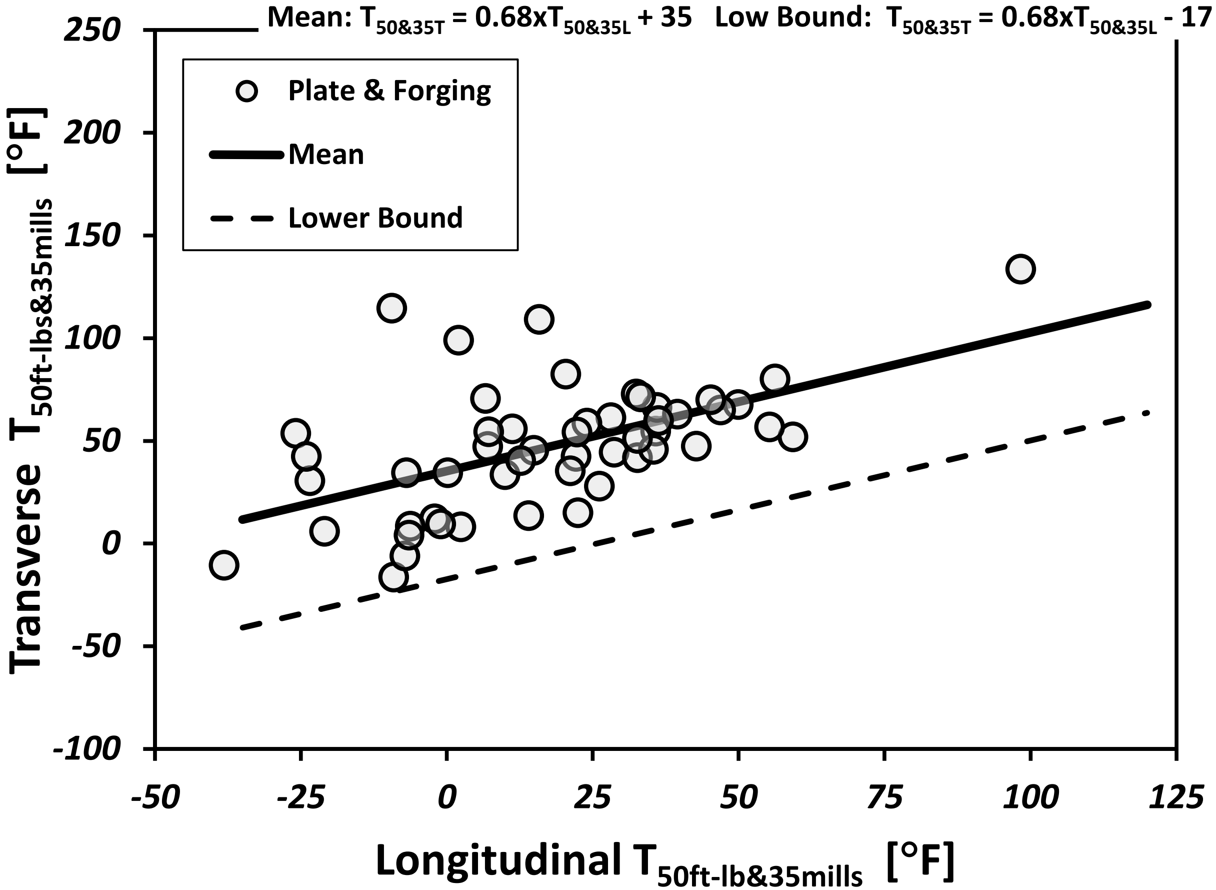

Preliminary analysis suggests that alternative formulae could be developed to convert longitudinal to transverse T_{50} values in a manner that is always conservative.

Raw Data

Position 1.1(4)

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Quotation

If limited Charpy V-notch tests were performed at a single temperature to confirm that at least 41 J (30 ft-lbs) was obtained, that temperature may be used as an estimate of the RT_{NDT} provided that at least 61J (45 ft-lbs) was obtained if the specimens were longitudinally oriented. If the minimum value obtained was less than 61 J (45 ft-lbs), the RT_{NDT} may be estimated as 11 °C (20 °F) above the test temperature.

Tests Required

Limited longitudinally oriented CVN tests at a single temperature

Interpretation

Define:	T_{TEST} =	the temperature at which limited longitudinally oriented CVN tests were conducted
	C_V =	absorbed energy observed at T_{TEST}
IF	$C_V \geq$	45 ft-lbs then $RT_{NDT} = T_{TEST}$
ELSE	$RT_{NDT} = T_{TEST} + 20$ °F	

When assessed using data sets for which full Charpy energy curves are available, EG&G interpreted Position 1.1(4) as having 2 possible meanings:

- $RT_{NDT} = T_{45(LONG)}$, and
- $RT_{NDT} = T_{30(LONG)} + 20$ °F

These might not produce the same result. Therefore, both were assessed.

Position 1.1(4)

Assessed for Forgings

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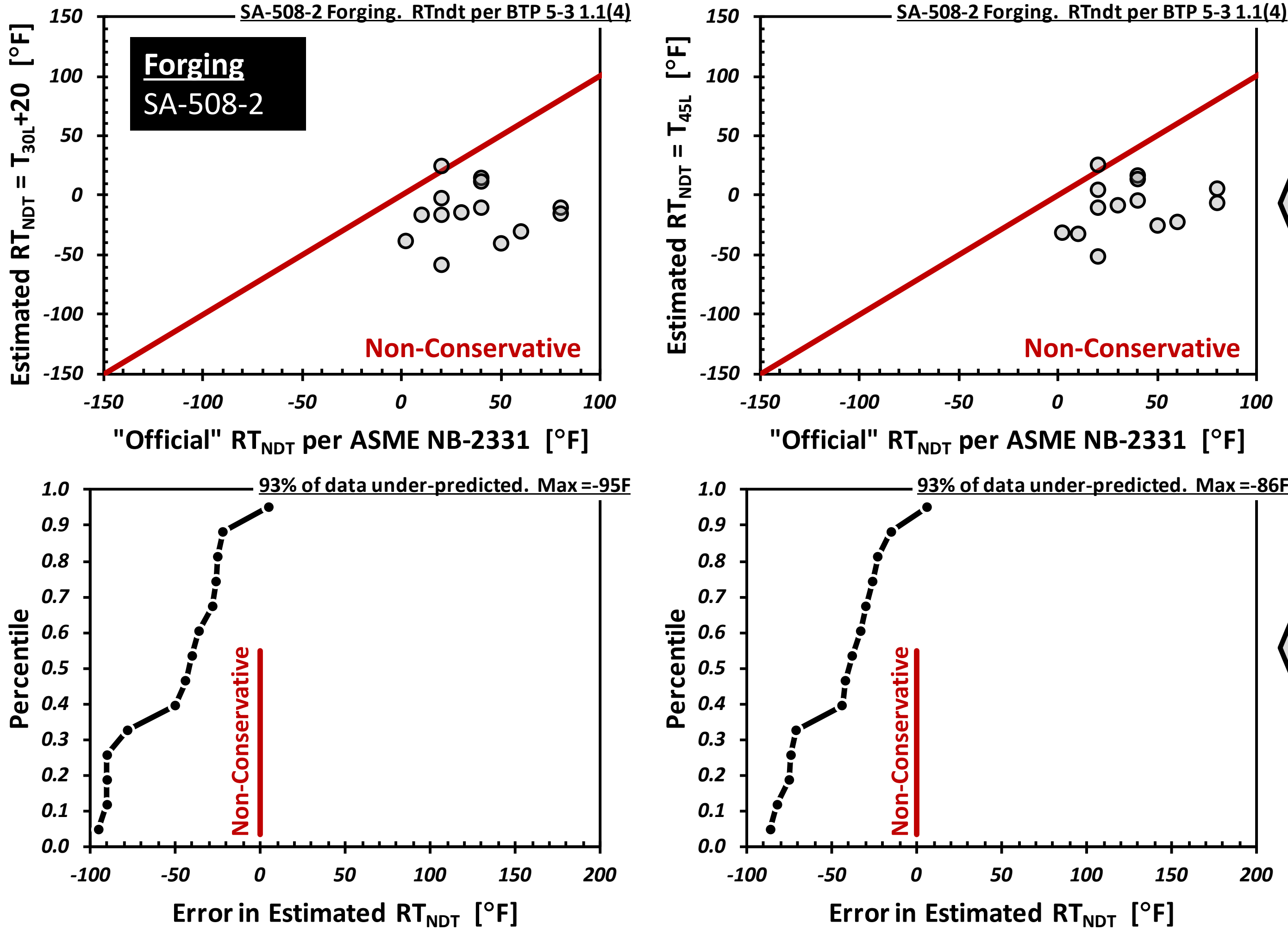
$RT_{NDT} = T_{30(LONG)} + 20\ °F$ | $RT_{NDT} = T_{45(LONG)}$



Top & bottom panel of each pair are the same data plotted two different ways

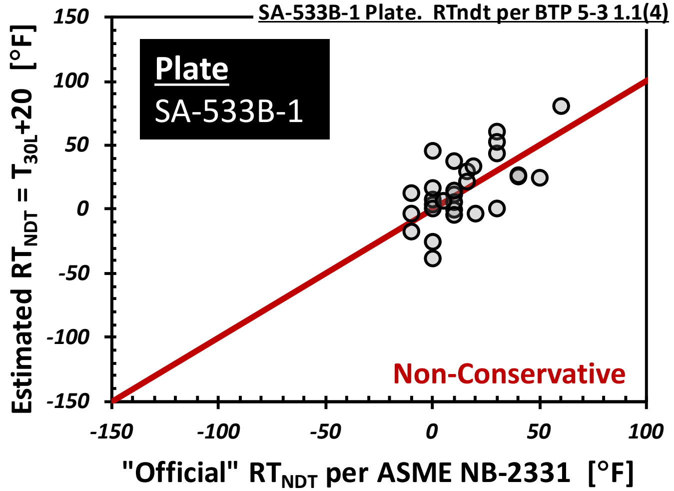
Position is non-conservative about 90% of the time

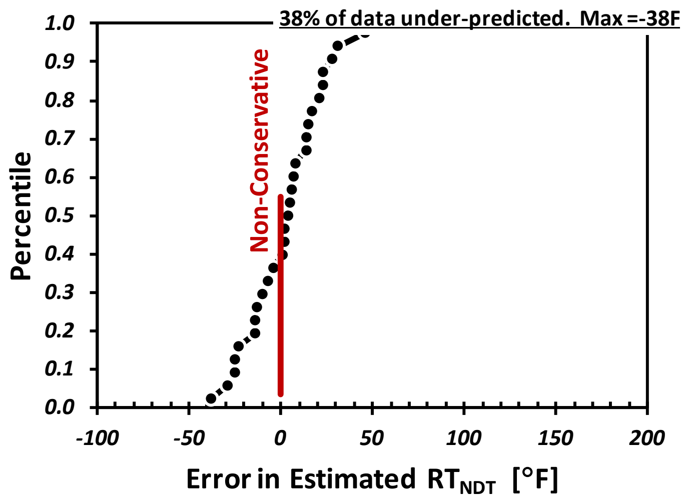
EG&G Data

Position 1.1(4)

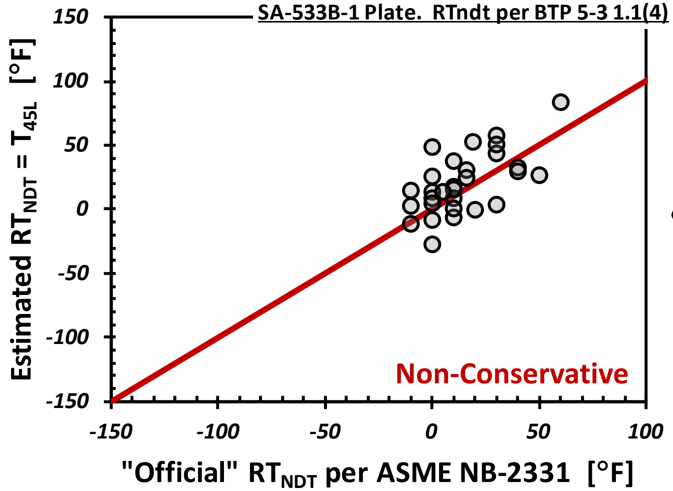
Assessed for Plates

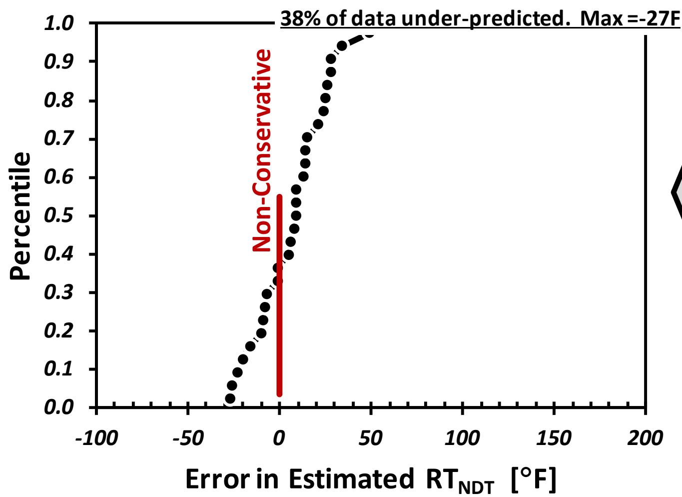
$RT_{NDT} = T_{30(LONG)} + 20$ °F





$RT_{NDT} = T_{45(LONG)}$





Top & bottom panel of each pair are the same data plotted 2 different ways

Position is non-conservative about 40% of the time

EG&G Data

Position 1.2

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Quotation

For the beltline region of reactor vessels, the upper shelf toughness must account for the effects of neutron radiation. Reactor vessel beltline materials must have Charpy upper shelf energy, in the transverse direction for base material and along the weld for weld material according to the ASME Code, of no less than 102 J (75 ft-lbs) initially and must maintain Charpy upper shelf energy throughout the life of the vessel of no less than 68 J (50 ft-lbs).

If Charpy upper shelf energy values were not obtained, conservative estimates should be made using results of tests on specimens from the first surveillance capsule removed.

If tests were only made on longitudinal specimens, the values should be reduced to 65% of the longitudinal values to estimate the transverse properties.

Tests Required

Longitudinally oriented CVN specimens tested on the upper shelf.

Clear Interpretation

$$USE_{TRANS} = 0.65 \times USE_{LONG}$$

where

USE_{LONG}	is CVN energy measured by longitudinally oriented specimens on the upper shelf
USE_{TRANS}	is the estimated CVN energy for transversely oriented specimens on the upper shelf

Position 1.2

Assessing: $USE_{TRANS} = 0.65 \times USE_{LONG}$

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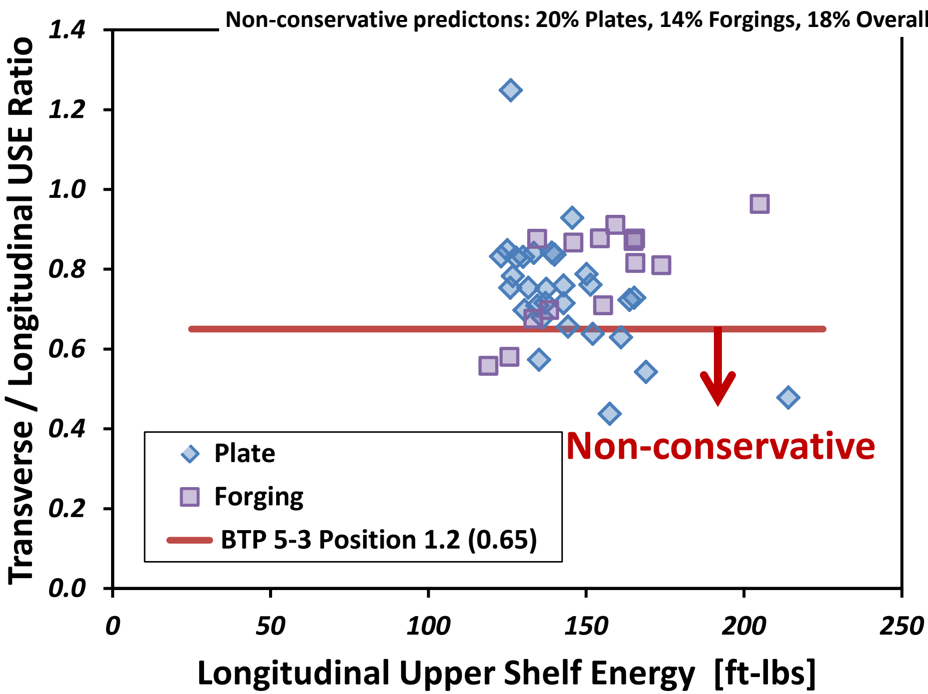
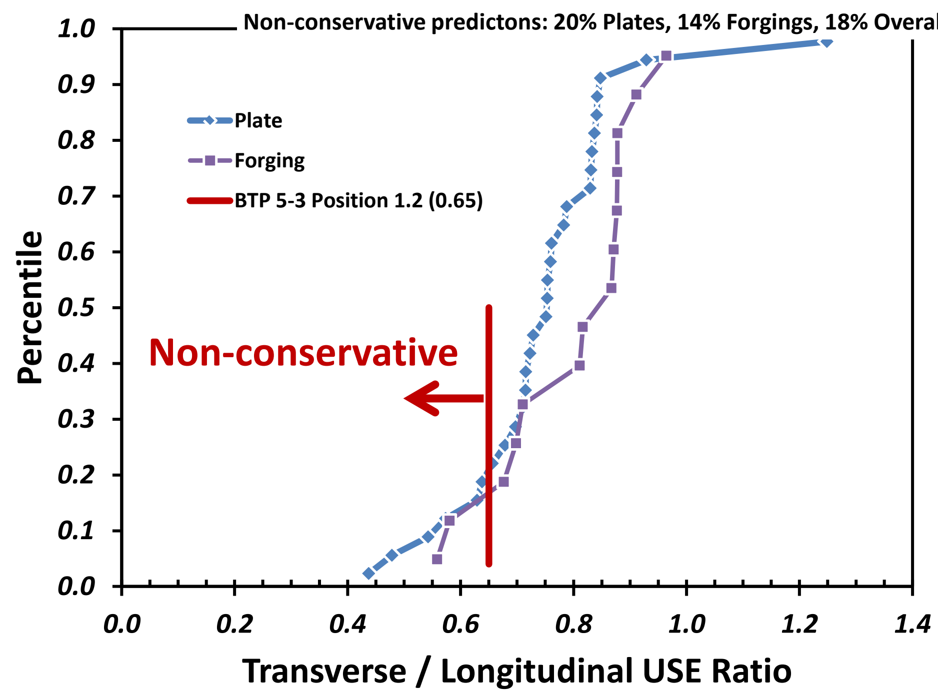
Same data plotted two different ways





Position is non-conservative about 18% of the time

EG&G Data

Position 1.2

Assessing: $USE_{TRANS} = 0.65 \times USE_{LONG}$

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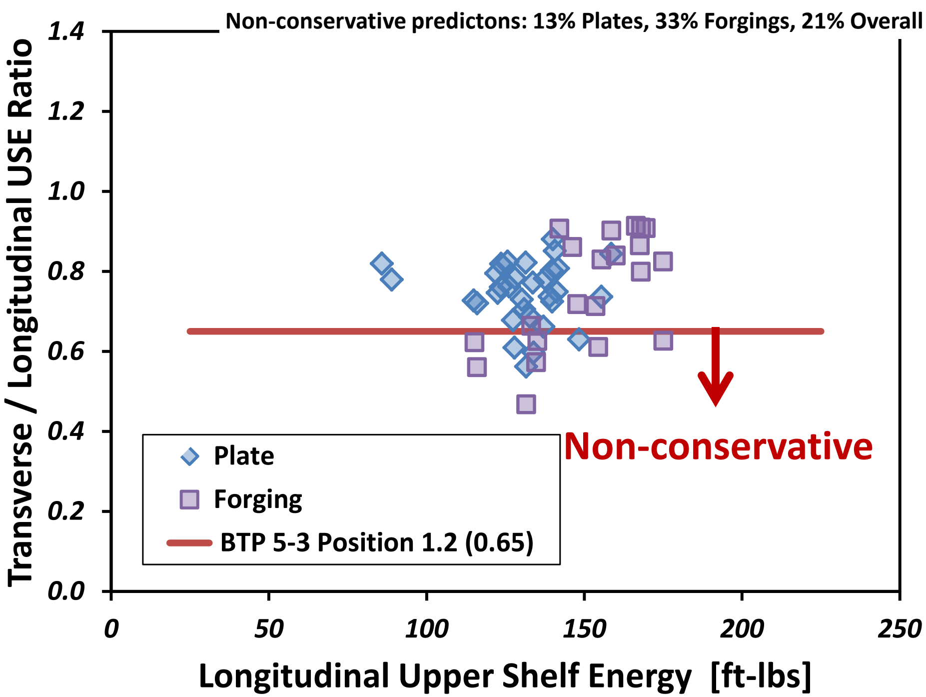
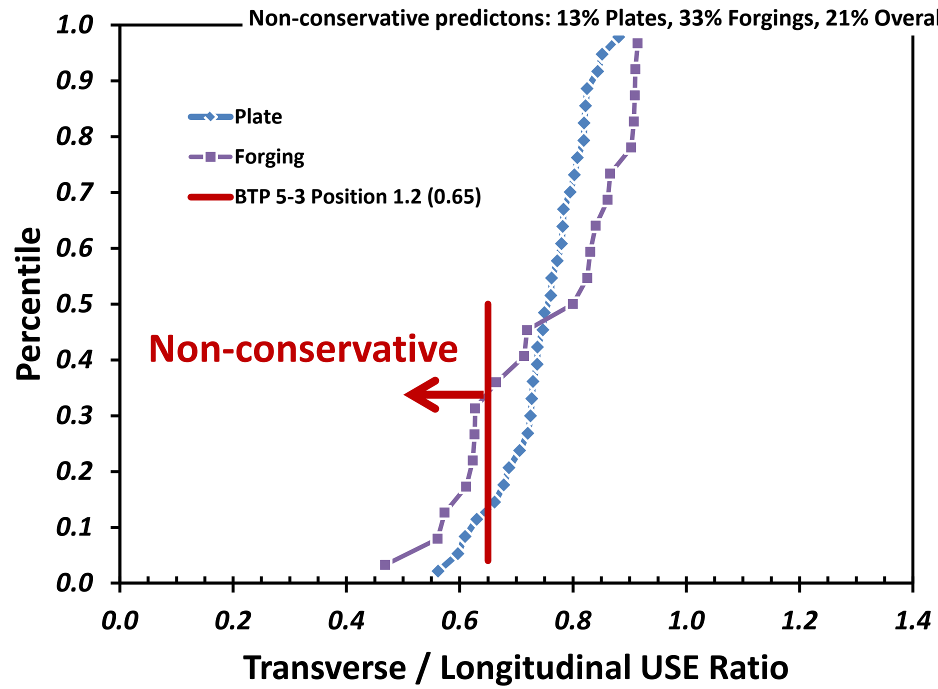
Same data plotted two different ways



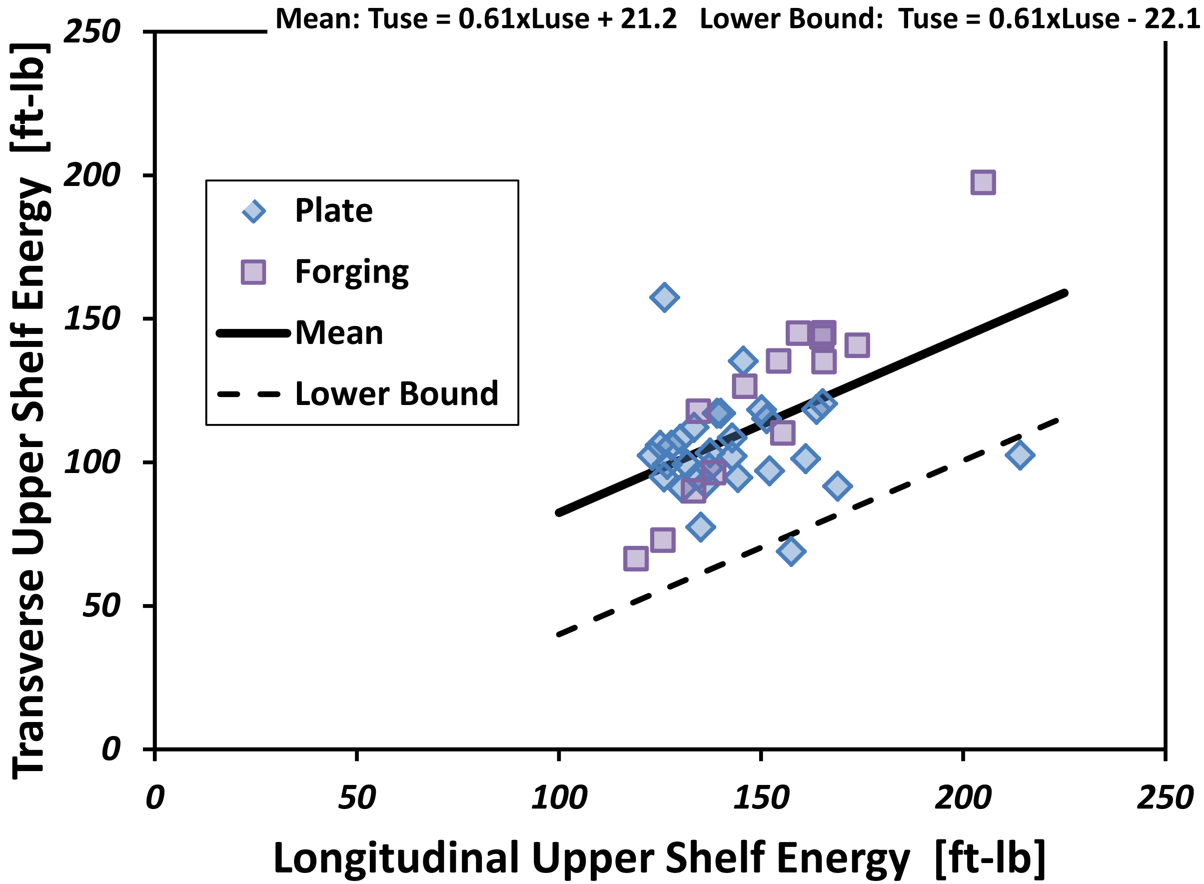


Position is non-conservative about 21% of the time

Raw Data

Position 1.2

Assessing: Alternative USE_{TRANS} Estimates

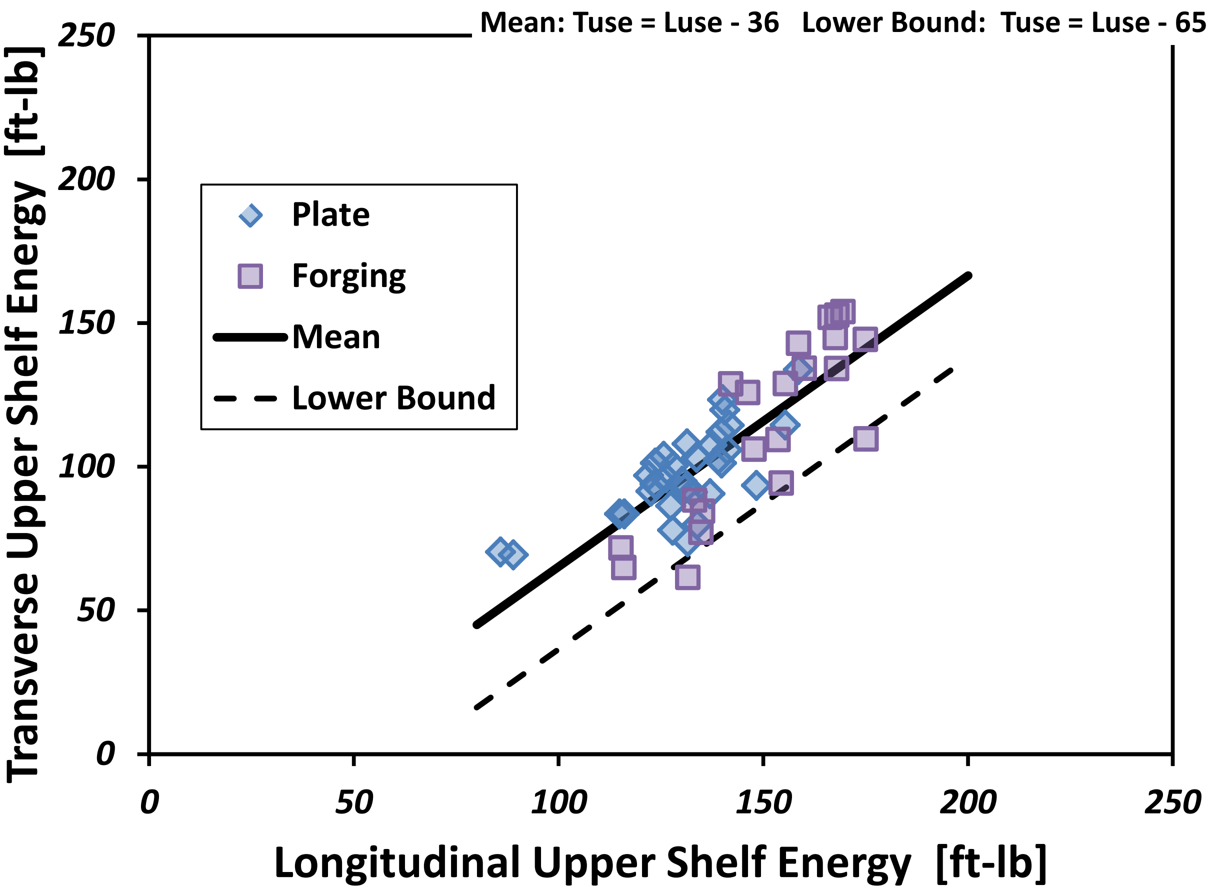


Preliminary analysis suggests that alternative formulae could be developed to convert longitudinal to transverse USE values in a manner that is always conservative.

EG&G Data

Position 1.2

Assessing: Alternative USE_{TRANS} Estimates



Preliminary analysis suggests that alternative formulae could be developed to convert longitudinal to transverse USE values in a manner that is always conservative.

Raw Data

Summary on Part I – Technical Evaluation

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- Positions 1.1(3) and 1.2
  - Results of the two studies are similar
  - Staff analysis confirms non-conservatism
- Position 1.1(4)
  - EG&G report demonstrates position is non-conservative
  - Awaiting NDTT data from Archives to complete staff assessment

Position of BPT 5-3		Forging Non-Conservative Prediction Rate		Plate Non-Conservative Prediction Rate	
		EG&G Data	Raw Data	EG&G Data	Raw Data
1.1(3)	(a) TRANS = 0.65×LONG	43%	48%	33%	19%
	(b) $T_{C(TRANS)} = T_{C(LONG)} + 20$ °F	50%	57%	70%	63%
1.1(4)	$RT_{NDT} = T_{45(LONG)}$	93%	TBD	38%	TBD
	$RT_{NDT} = T_{30(LONG)} + 20$ °F	93%	TBD	38%	TBD
1.2	$USE_{TRANS} = 0.65 \times USE_{LONG}$	14%	33%	20%	13%

Part II: Assess Potentially Affected Plants - Position 1.1(3)

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Plant Identification

- Search RVID for plants using BTP 5-3 to determine plate (forging) $RT_{NDT(u)}$:

  20 operating plants

- Rank plates (forging) according to the difference between RT_{PTS} at 32 EFPY and 270 °F:

  Eight plants have their limiting plates or forgings using BTP5-3 with difference less than 100 °F.

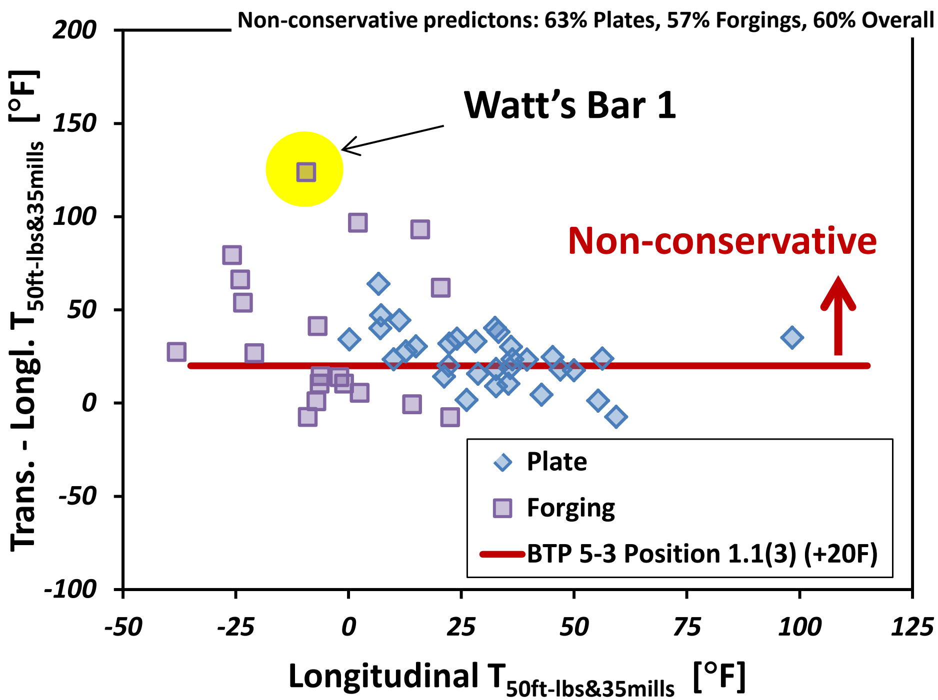
Plant-specific evaluation results

- The majority of the plants did not specify which BTP 5-3 B1.1 position was used in determining their $RT_{NDT(u)}$ values
- Details of calculation of $RT_{NDT(u)}$ values are not available.
- One plant has full transverse Charpy data and the staff confirmed that BTP 5-3 was not used , so it will be dropped from the list
- A few plants have full longitudinal Charpy data
  - The staff's $RT_{NDT(u)}$ values using lower bound Charpy data and linear interpolation between two temperatures are lower than the licensee's value by 10 °F
- A few plants may have PTS concern because the RT_{PTS} values are below 270 °F by less than 75 °F
  - In one case, the longitudinal Charpy data for one plate are significantly higher than other plates, indicating potential mislabeling

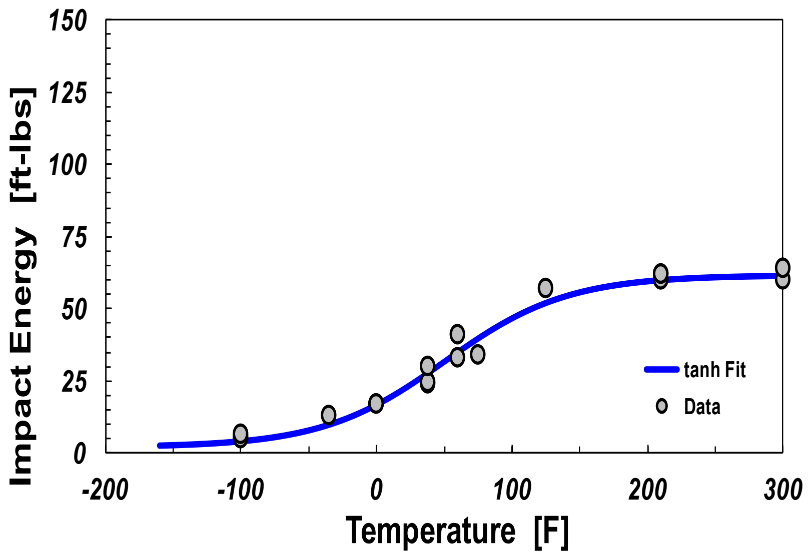
Why do we use the Selecting criterion of 75 °F?

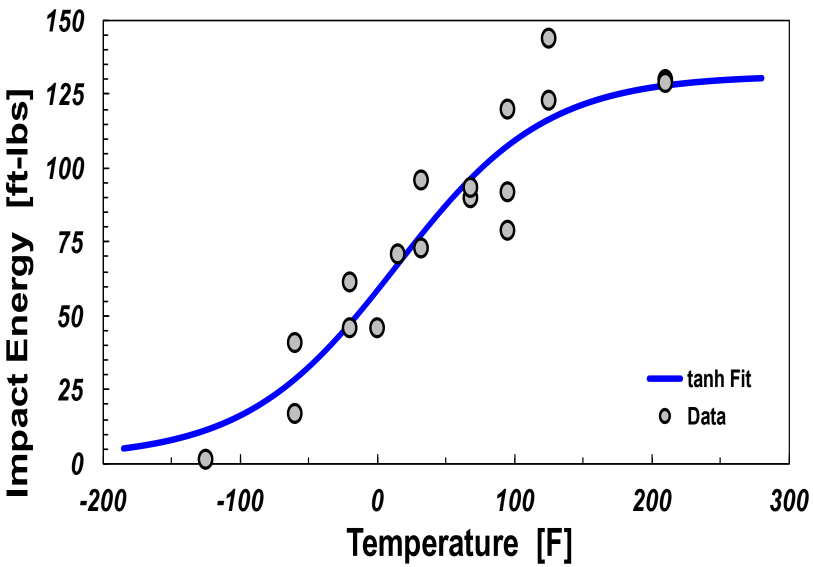
- Identify raw data with the greatest conservatism and non-conservatism

Watts's Bar 1 – greatest non-conservatism
Millstone 2 – greatest conservatism



Closer Look at the Charpy Data with the Greatest Non-Conservatism





T_{50flb} [°F]	T_{35mill} [°F]
114.5	83.0

<u>Transverse Data</u>

T_{50flb} [°F]	T_{35mill} [°F]
31	-

<u>Longitudinal Data X .65</u>

T_{50flb} [°F]	T_{35mill} [°F]
-15.5	-9.4

<u>Longitudinal Data</u>

Determine the RT_{NDT} for the Raw Data with the Greatest Non-Conservatism

- Nil-ductility transition temperature (NDTT): -22 °F
- Official $RT_{NDT(u)}$ value: = 54.5 °F
  (114.5 °F - 60 °F)
- $RT_{NDT(u)}$ based on BTP 5-3B1.1(3)a: -22 °F
  (At 31 °F, the equivalent Charpy energy (.65 x longitudinal data) is 50 ft-lb; RT_{NDT} = NDTT)
- $RT_{NDT(u)}$ based on BTP 5-3B1.1(3)b: -22 °F
  (At -15.5 °F, the Charpy energy is 50 ft-lb; since the adjusted temp is (-15.5 °F + 20 °F), less than (-22°F + 60 °F), RT_{NDT} = NDTT)

Summary on the Study Focusing on the Raw Data with the Highest Non-Conservatism

- The highest non-conservative raw data is about 75 °F
- RT_{NDT} determination is not sensitive to whether B1.1(3)a or B1.1(3)b is used for this case
- RT_{NDT} determination is affected by whether curve fitting of the entire Charpy data or hand calculations based on Charpy data at two temperatures are used

Part II: Assess Potentially Affected Plants - Position 1.2

- **Plant Identification**
  - 45 operating plants identified in RVID as using Position 1.2
  - RVID clearly identifies Position 1.2 as *UNIRR_USE_METHOD*=65%
  - Spot-checking of RVID references to confirm accuracy still TBD
- **Non-conservatism**
  - Data analysis shows the Position 1.2 estimate to be non-conservative between 13% and 33% of the time

Next Steps

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NRC

- **Complete technical analysis**
  - Need NDTT data from Archives to complete assessment of Position 1.1(4)
  - Investigate GE $RT_{NDT(u)}$ procedure
  - Document findings
- **Complete plant assessment**
  - Need to assess the impact to Pressure-temperature limits
  - Recommend to NRC management regarding use of interim conservatism in defining $RT_{NDT(u)}$ for the plants which may need to update their PTS evaluations
- **Communicate findings to affected plants**
  - Precise means TBD
- **May need to revise BTP 5-3 in Standard Review Plan**

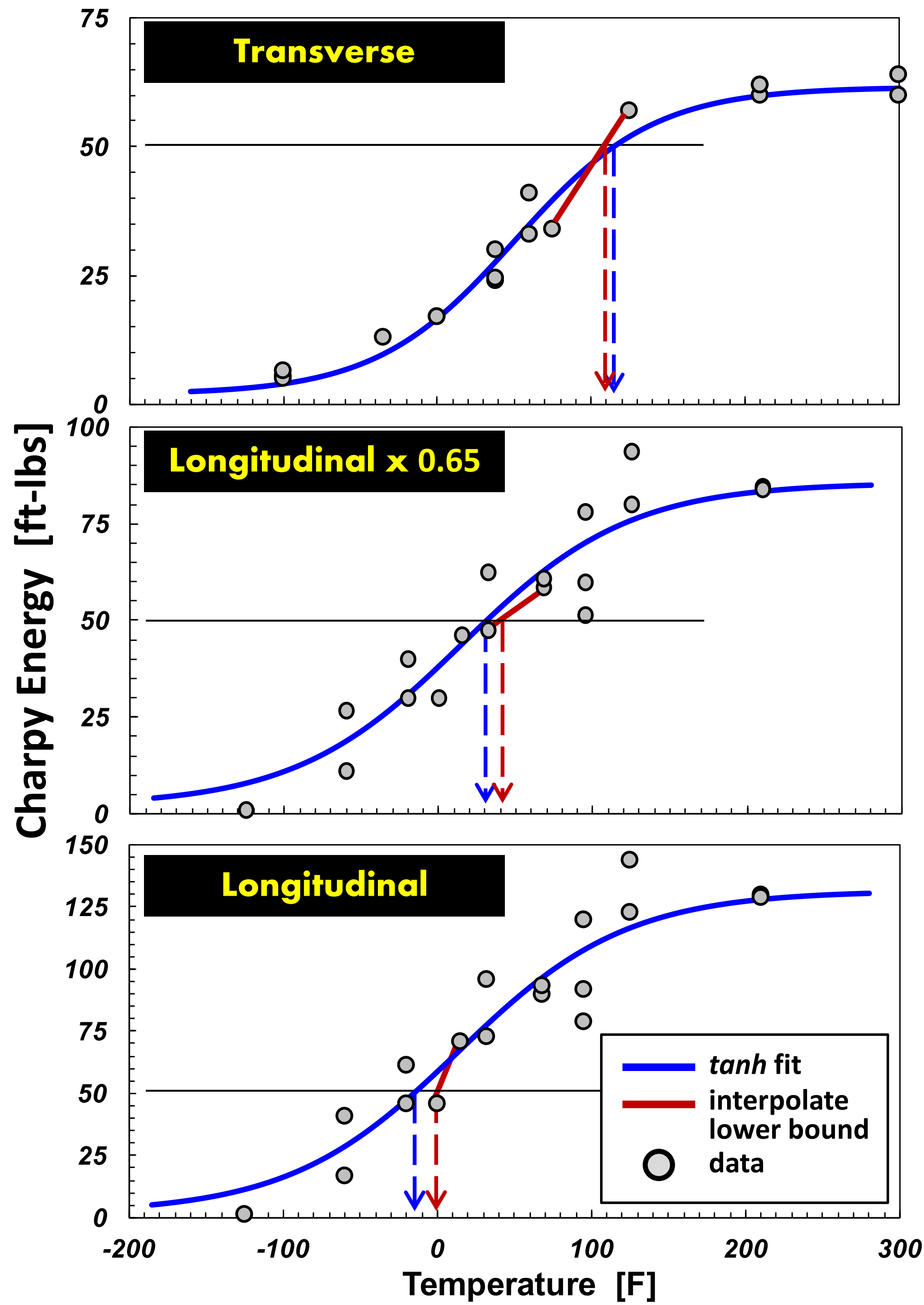
Industry

- **Assess the impact of reported potential non-conservatism including the need to redefine the $RT_{NDT(u)}$ on pressure-temperature limits and PTS evaluations**

BACKUP SLIDES

Comparison of Charpy Fit Methods

Method	NDTT [°F]	Meas. T_{50} [°F]	Trans. T_{50} [°F]	RT_{NDT} [°F]	Non Conservatism [°F]
Charpy Fit Method: *tanh* (mean)					
NB-2331	-22	114.5	114.5	54.5	---
1.1(3)a: Energy*0.65	-22	31	31	-22	76.5
1.1(3)b: $T_{50(LONG)}$+20 °F	-22	-15.5	4.5	-22	76.5
Charpy Fit Method: Interpolate lower bound data					
NB-2331	-22	109.5	109.5	49.5	---
1.1(3)a: Energy*0.65	-22	41	41	-19	68.5
1.1(3)b: $T_{50(LONG)}$+20 °F	-22	0	20	-22	71.5



Main Points

- There is some effect of *tanh* fitting versus lower-bound interpolation
  - Interpolation can produce higher or lower transition temperature values than *tanh* fitting
- Using either Charpy fitting method, BTP 5-3 Position 1.1(3) is non-conservative